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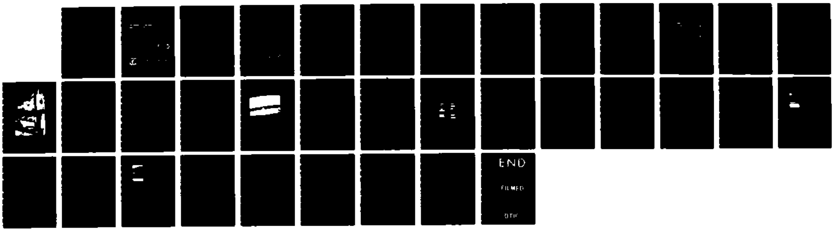

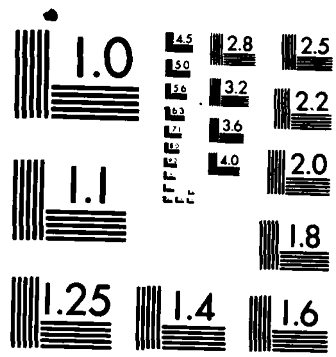

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HIGH SENSITIVITY, ONE-SIDED X-RAY INSPECTION SYSTEM

BY H. BERGER Y. T. CHENG E. L. CRISCUOLO
(INDUSTRIAL QUALITY, INC.)

FOR NAVAL SURFACE WEAPONS CENTER
RESEARCH AND TECHNOLOGY DEPARTMENT

JULY 1985

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A backscatter x-ray imaging method for nondestructive testing has been developed. The one-sided inspection technique, a slot camera, is much faster in response than previous backscatter methods. Delaminations in graphite-epoxy composites and other low atomic number materials have been detected. Wall thicknesses up to 7 cm thick have been interrogated. The results show the location (depth) and magnitude (separation width) of simulated delaminations throughout the entire wall. A disbond between two flat surfaces in contact has been detected. Feasibility of the system has been shown with film detectors. A fast-

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response electronic detector is proposed.

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EXECUTIVE SUMMARY

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The objective of this program was to demonstrate the feasibility of an x-ray inspection equipment capable of probing an inspection sample from only one side to detect delaminations, voids, cracks or foreign material through the thickness interrogated. The feasibility of a unique, patented x-ray slot camera that works by scattered radiation was demonstrated using film techniques. The unique capability of this slot camera is that it can obtain images of the internal structure of an object at depths of many centimeters (depending on the object density and the x-ray energy) with a sensitivity that is several orders of magnitude greater than past-developed scattered radiation cameras. The program has shown that delaminations in flat test samples can be detected, sized and located even when the delamination faces of the test sample are in physical contact. Further, experiments with actual samples of graphite-epoxy rocket motor cases have shown that delaminations in this real structural material can be detected. Experiments to date indicate that the slot camera will detect multiple delaminations through thicknesses of 7 cm (2.75 inch) or more and provide data for the depth and width of each delamination. Further experiments demonstrated that the slot camera has the capability of magnifying the images of delaminations, equivalent to improving the spatial resolution, simply by changing the distance from the camera slot to the image plane. The information gained in the Phase I program with a film image detector, leads logically to a Phase II program, in which a high sensitivity, electronic, real-time imaging panel will be developed. Preliminary designs for the imaging panel indicate that the electronic detector will increase the camera sensitivity for detection of x-rays by three orders of magnitude over that of x-ray film. Such a digital camera will provide much faster and more quantitative results than the film used in the feasibility study. In addition, the camera will operate in real-time so that an inspection can be done quickly while a motor is rotated past the inspection station. Multiple inspection stations are feasible as a means to further shorten the inspection time for a large rocket motor. For the particular problem of inspecting fiber composite rocket motor pressure vessels, the anticipated backscatter x-ray instrument will offer high sensitivity (contact delaminations have been detected), fast response (the electronic detector will provide real-time capability), and inspection through the thickness of the rocket motor case wall in a single view (multiple delaminations through a sample thickness of 7 cm have been demonstrated). In addition, the new x-ray slot camera will provide quantitative information about discontinuity depth, location and size.

FOREWORD

This document reports the results of a six-month Small Business Innovation Research (SBIR) program investigation directed toward the problem of assessing damage in composite pressure vessels as used in rocket motors. Program support was from SBIR funds. The approach reported involved an x-ray backscatter imaging technique. The results showed that delaminations and other variations in density of an interrogated wall can readily be detected by the one-sided x-ray slot camera, a novel patented variation of a pin-hole camera. The slot camera offers better speed of response as compared to other backscatter approaches and offers the significant advantages of displaying the entire wall thickness and any variations in one view. The data yield information about delaminations (or other density variations), their depths from the front surface and the extent of the variation into the wall. The extremely small variation of two flat surfaces in contact has been detected by this sensitive technique. A follow-on study has been proposed to investigate an electronic detector instead of the film detector used in this feasibility investigation. An electronic detector offers the prospect of a rapid response, quantitative, real-time inspection system.

Approved by:

J. R. Dixon

JACK R. DIXON, Head
Materials Division

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Cont.)

TABLES

INTRODUCTION

An x-ray inspection method that makes use of x-rays scattered from the inspected object is described. A camera with a slot collimator (instead of pin-holes as in past cameras) offers much improved speed of response for imaging scattered radiation. The collimation of the interrogating x-ray beam and the field of view of the imaging camera provide a means to locate a defect and to size it. The technique is particularly useful for laminar defects which often present problems for other nondestructive inspection techniques. Examples include cracks, voids and disbonds in structures such as missile rocket motors, aircraft bonded panels and ordnance items.

In the original proposal (January 9, 1984), it was pointed out that the backscatter slot camera was well suited to the problem addressed in the Phase I program, namely the assessment of composite pressure vessel damage (Defense SBIR Solicitation 84.1, Navy Topic No. 91). Such damage will typically result in internal delaminations and cracks in the composite wall itself, or in a rocket motor, as delaminations between the motor case and rubber liner or between the rubber liner and propellant. The Phase I feasibility program has demonstrated that the backscatter x-ray instrument will detect such anomalies quickly, effectively and in a quantitative manner. Further, as compared to other nondestructive testing approaches, the x-ray slot camera provides a one-sided, practical inspection of the total thickness of the inspected wall in a single view. The technique gives information which is, in effect, a backscatter tomograph. Competitive approaches, such as conventional tomography (computerized axial tomography), or single point scatter techniques, require much more extensive instrumentation and time to yield similar information, and are more expensive for accomplishing the necessary nondestructive inspection. The presentation of the delaminations in the total wall thickness, as given by the slot camera, not only speeds the inspection but also enhances interpretation of the inspection data.

The initial investigation to show the feasibility of the x-ray slot camera is described in this report. Experiments were conducted to demonstrate with film the capability of the camera to detect, size and locate density variations throughout the thickness of an inspected wall. Quantitative information about delamination width and depth is presented. The experiments include several imaging geometries and demonstrate magnification and minification of the scatter image. These factors are particularly appropriate to the discussion for a preliminary design of an electronic detector; this would allow the x-ray slot camera to operate as a real-time inspection system.

An electronic detector, slot camera instrument will be useful in many inspection situations. High sensitivity, quantitative inspection information and access from only one side are all significant advantages for the slot camera inspection system. Applications include inspection of components for ships, aircraft, surface vehicles, buildings, etc. in addition to the rocket applications discussed. Sensitivity to laminar-type defects, as has been demonstrated here, is particularly important in many of these inspection applications. Systems designed for field inspections are possible.

PHASE I RESULTS

EXPERIMENTAL CONDITIONS

The Phase I program investigated the capability of a unique one-sided x-ray inspection system to detect delaminations in objects of interest. The two primary components of this system are an x-ray source which provides a collimated x-ray beam, and a slot camera which images the structure of the interrogated volume in the object. The geometry for this system is shown in Figure 1. The collimated x-ray beam is directed toward the object, and the x-rays which are scattered from the interrogated volume elements and which pass through the aperture of the slot camera, form a two-dimensional image of all of the interrogated volume elements in the object. The imaging pixel geometry of the slot camera is illustrated in Figure 2. The picture elements (pixels) at points 1 and 2 in the object (actually volume elements) are transformed into rectangular shaped, two-dimensional pixels at the image plane.

The collimated x-ray beam at the sample position has a rectangular shape which determines the slice thickness of the scanned image; this beam, together with the camera slot width determine the spatial resolution of the system. In these measurements, different beam collimators were used, and for most cases, the beam sizes at the position of the sample were 5 mm x 3 cm, and 2.5 mm x 2.5 cm, as shown by reproduced film images in Figure 3.

In this Phase I program, the images at the image plane in Figure 1 were detected by a conventional screen-film cassette. This simple image detection system was used in the slot camera as a first step in order to demonstrate the imaging capabilities of this one-sided system for inspecting lightweight materials used in rocket chambers, and in order to obtain basic data needed for the design of a real-time, fast response image detector panel to be developed in a Phase II program.

Photographs of the experimental equipment used in these Phase I studies, including the x-ray source, the object, and the screen-film cassette, are shown in Figure 4.

The experiments in Phase I were carried out with the following conditions and values for the parameters shown in Figure 1:

(a) X-ray source: 420 kV D.C. Seifert X-Ray Machine
Operating conditions: 200 kV and 250 kV, 1.8 mm focal spot diameter, 8 mA.

(b) Screen-Film cassette: DuPont Quanta III screens (12.7 x 17.8 cm, 5 x 7 inch) were used with DuPont NDT 89 film. Film was hand processed, 20 degrees C, 5 minutes.

(c) X-Ray target-object distance, L in Figure 1: 70 cm.

(d) X-Ray beam to slot distance, A in Figure 1: 20 cm.

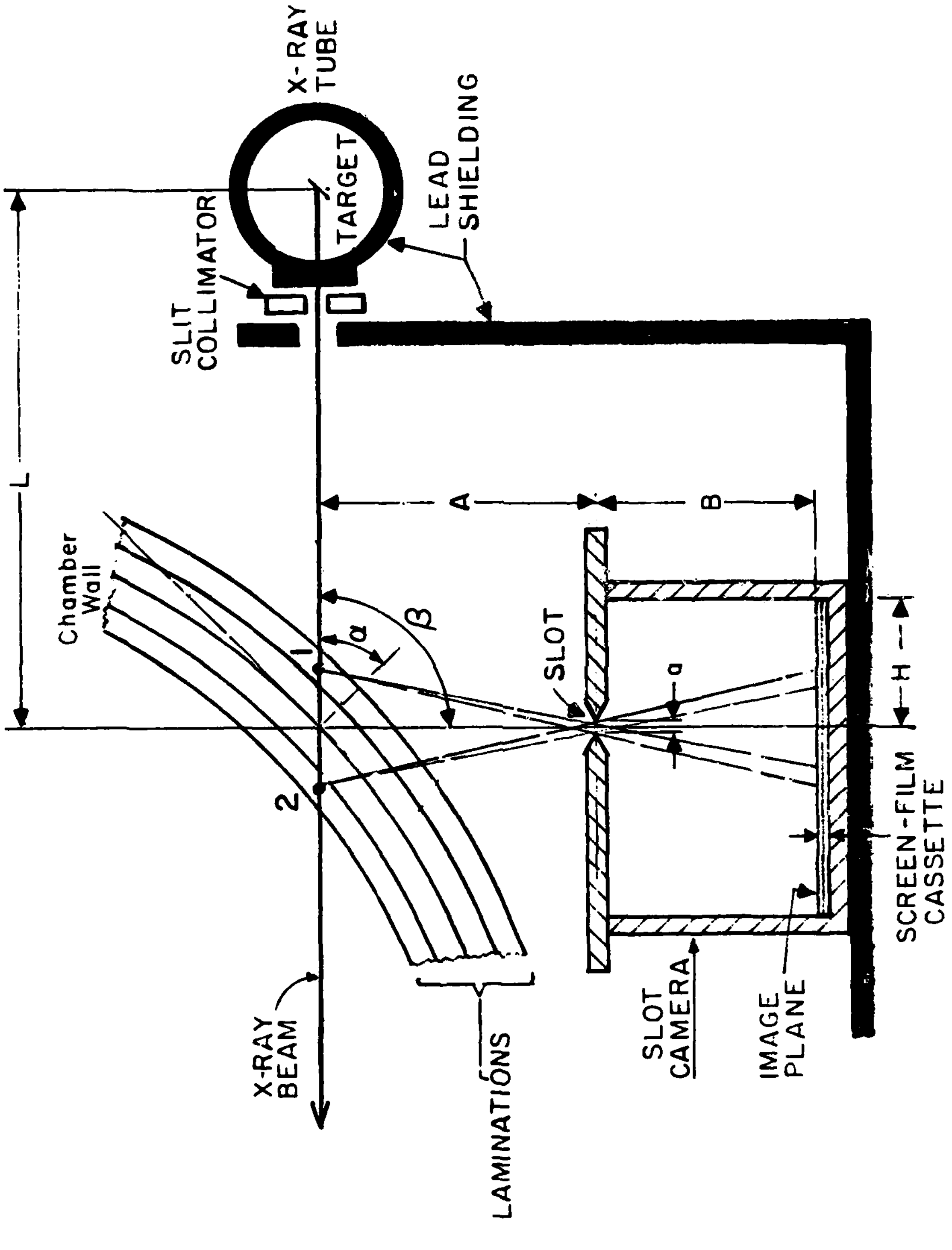

FIGURE 1. EXPERIMENTAL ARRANGEMENT AND GEOMETRY FOR ONE-SIDED X-RAY INSPECTION SYSTEM

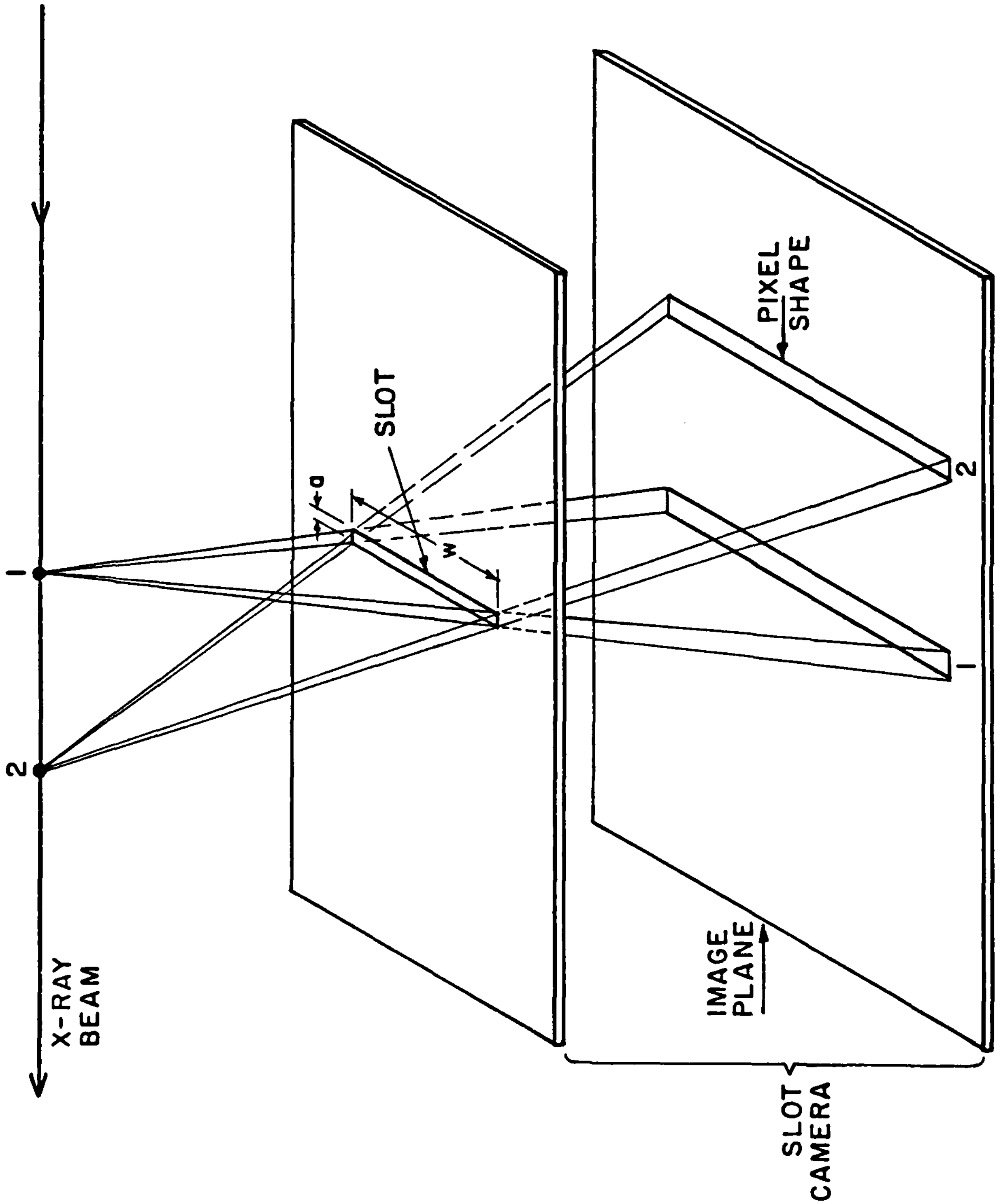

FIGURE 2. PIXEL GEOMETRY FOR THE SLOT CAMERA

FIGURE 3. IMAGES OF COLLIMATED BEAM SPOT AT SAMPLE FOR (UPPER) 0.5mm SOURCE SLIT AND (LOWER) 0.25mm SOURCE SLIT (20% REDUCTION AS SHOWN)

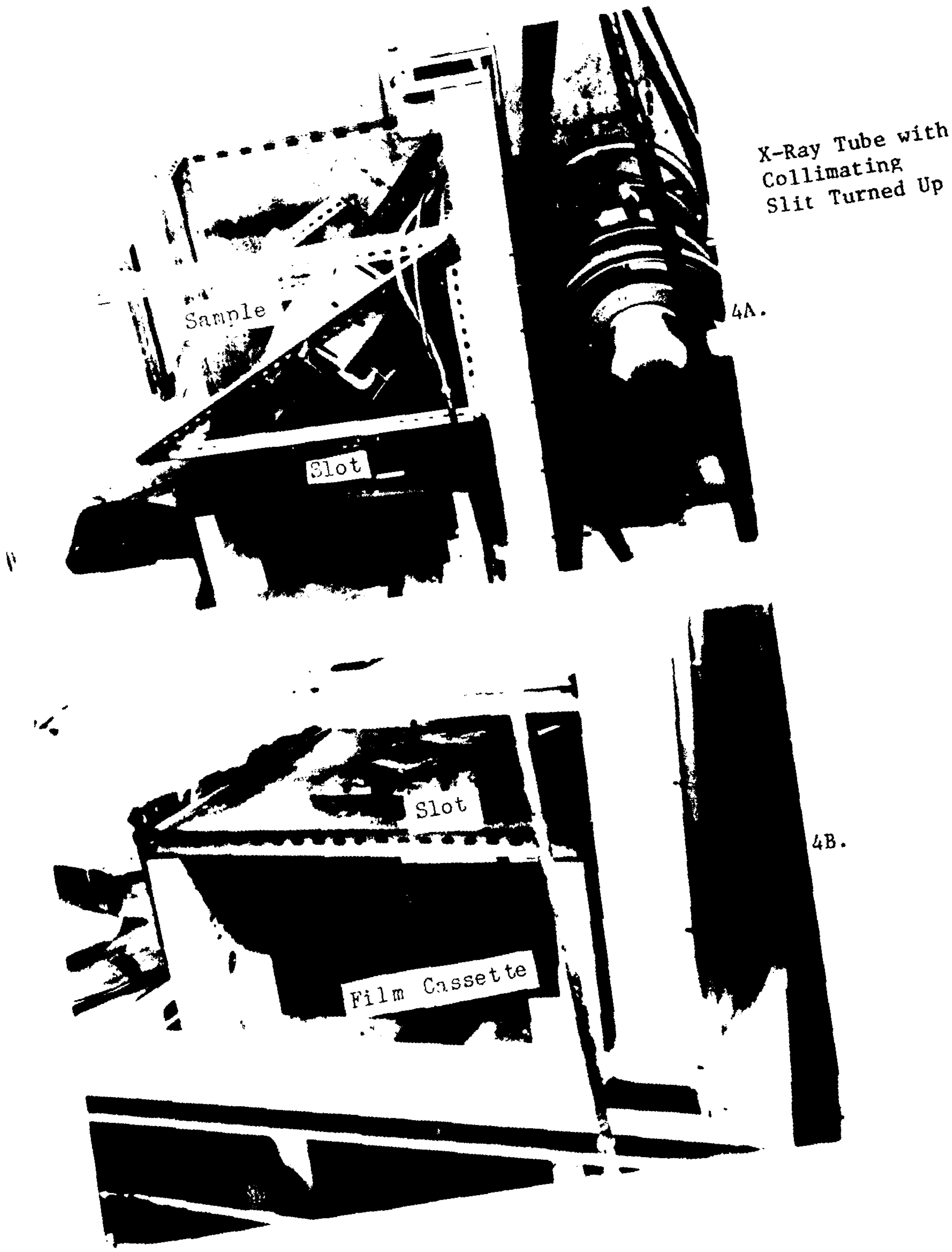

FIGURE 4. PHOTOGRAPHS OF BACKSCATTER X-RAY EQUIPMENT
4A. UPPER VIEW: COMPLETE SYSTEM. X-RAY UNIT TURNED UP TO SHOW SOURCE SLIT COLLIMATOR
4B. LOWER VIEW: FILM CASSETTE IN IMAGING POSITION

(e) Slot-image plane distance, B in Figure 1: 20 cm, 10 cm.

(f) X-ray incident angle, α, between direction of x-ray beam and normal to incident surface of object in Figure 1: 45 degrees, 60 degrees.

(g) Angle between x-ray beam direction and direction perpendicular to image plane, β, in Figure 1: 90 degrees, 105 degrees.

(h) Camera slot width, a, in Figure 1: 1 mm, 0.25 mm.

(i) X-ray collimator widths at the source: 1.0 mm, 0.5 mm, 0.25 mm.

TEST OBJECTS

For the initial measurements, simple test objects were constructed of Lucite[a] slabs in order to simulate the low density, low atomic number material used in a rocket motor chamber. These test objects were made by inserting spacers of given thicknesses at the edges between the Lucite slabs and then clamping the slabs together. With this arrangement, the separations between the slabs simulated delaminations of any specified size. The simplest test object, shown in Figure 5(A), consists of two Lucite slabs with different spacers that provided different gap sizes from 0.25 to 6 mm.

Multi-layer test objects (with several Lucite slabs) having different gap sizes simulating delaminations are shown in Figures 5(B) and 5(C). These test objects have a range of gaps from 0 to 2 mm, and total thicknesses of 60.8 mm and 73.5 mm. These simple test objects were used to test the capability of the one-sided x-ray inspection system to measure the separation size and the depth from the inspected surface that a flaw can be detected. These objects also demonstrated that many discontinuities at different depths in the test object can be detected in a single inspection view.

The anticipated application of this inspection system involves the detection of flaws that may exist in rocket motor chambers. The chamber material consists of a filament-wound Kevlar or graphite epoxy composite with a rubber liner bonded to the inner surface. The thickness of the composite varies from approximately 0.63 cm (1/4 inch) to 7.6 cm (3 inches), and the thickness of the rubber liner varies from approximately 0.63 cm (1/4 inch) to 1.9 cm (3/4 inch). A diagram and a photograph of a small section (30 cm x 30 cm) of such a graphite-epoxy test object to simulate a motor chamber as used in these measurements, is shown in Figures 6A and 6B, respectively. Delaminations were simulated in the graphite-epoxy material by clamping together pieces of the laminate structure that had pulled apart in other tests.

EXPERIMENTAL RESULTS

The first set of experiments was carried out with the simple two-block test object shown in Figure 5(A). A series of x-ray exposures was made with the following different gap sizes to simulate delaminations: 0.25, 0.50, 1.0, 2.0, 4.0 and 6.0 mm. The conditions for this set of exposures are summarized in Table 1.

a. Trade name; no endorsement is implied.

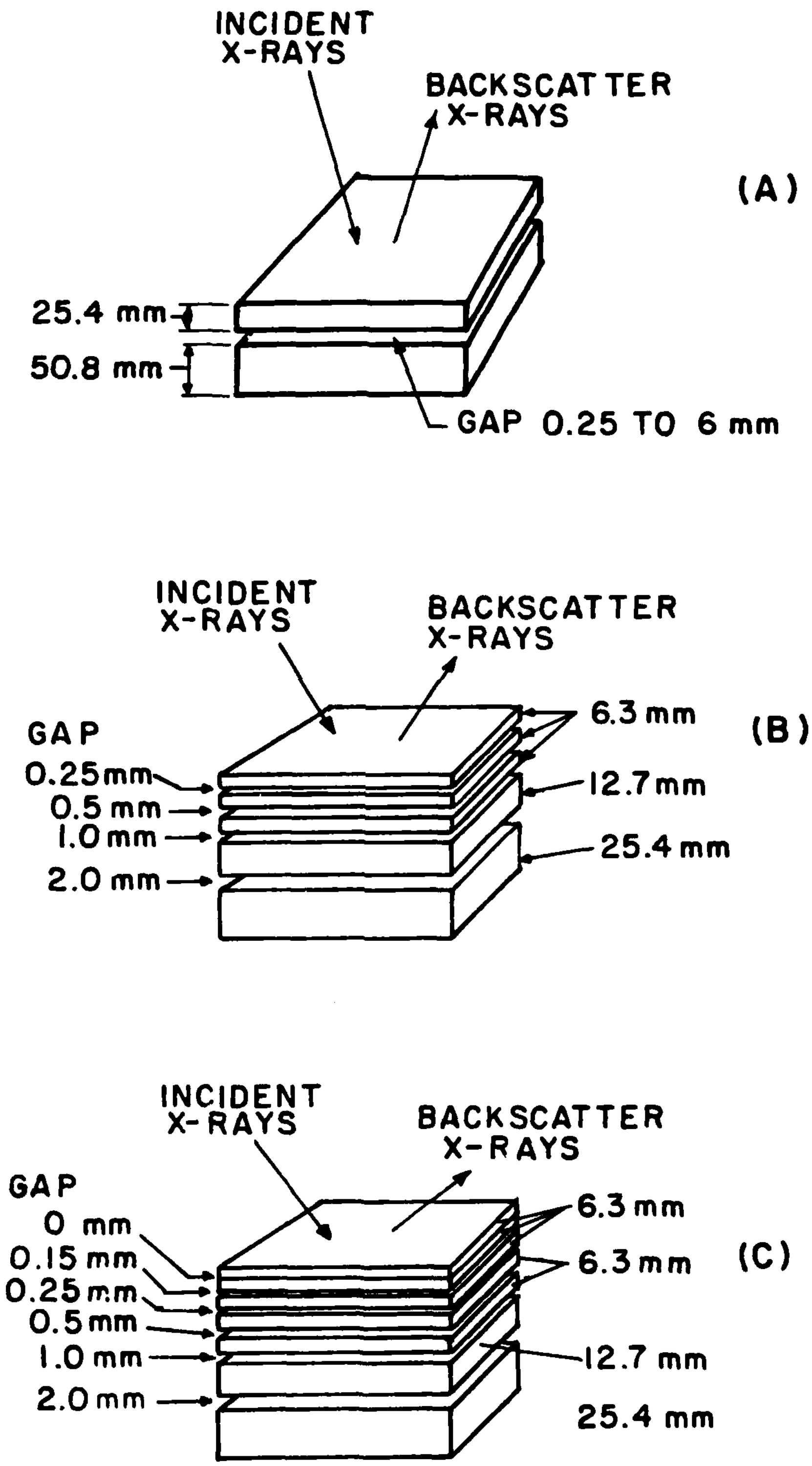

FIGURE 5. LUCITE TEST OBJECTS

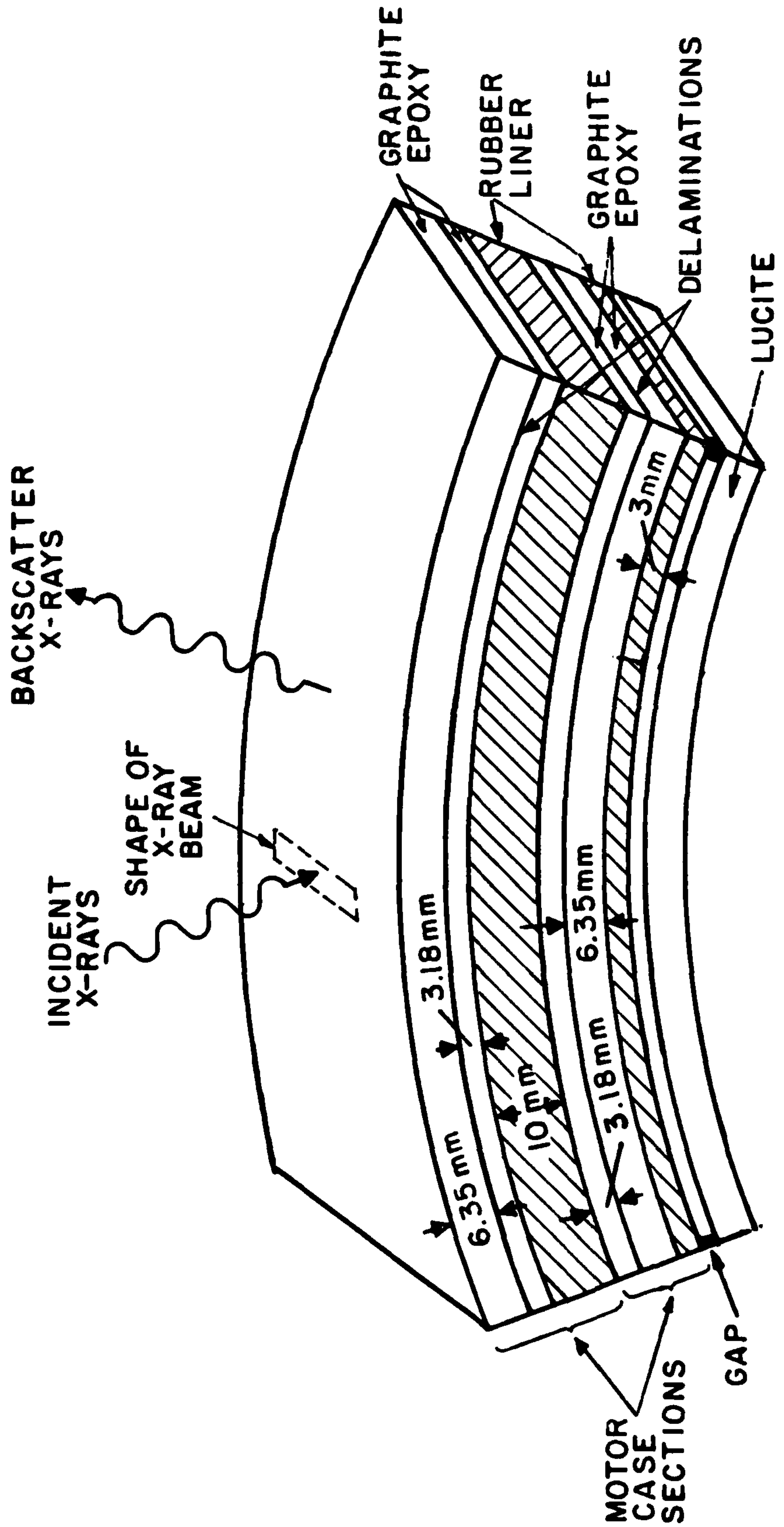

FIGURE 6A. CLAMPED SECTIONS OF GRAPHITE-EPOXY-RUBBER-LUCITE LAYERS TO SIMULATE A MOTOR CASE

FIGURE 6B. A PHOTOGRAPH SHOWING AN EXPLODED (UNCLAMPED) VIEW OF THE SEVERAL SECTIONS OF GRAPHITE-EPOXY-RUBBER USED FOR THE TEST OBJECT AS SHOWN CLAMPED TOGETHER IN FIGURE 6A

TABLE 1. EXPOSURE CONDITIONS FOR TEST OBJECTS

TEST OBJECT, FIGURE	X-RAY SOURCE, kVCP	mA	X-RAY BEAM COLLIMATOR WIDTH AT SOURCE	CAMERA SLOT WIDTH, a	CAMERA GEOMETRY (FIGURE 1) α (DEG.)	β (DEG.)	A (CM)	B (CM)	EXPOSURE TIME MINUTES
5(A)	200	8	1 mm	1 mm	45	90	20	20	20
5(B)	250	8	0.5 mm	1 mm	45	90	20	20	40
5(B)	250	8	0.5 mm	1 mm	60	105	20	20	60
5(B)	250	8	0.5 mm	1 mm	45	90	20	10	40
5(C)	250	8	0.25 mm	1 mm	45	90	20	20	80
6(A)	250	8	0.25 mm	1 mm	45	90	20	20	123

Contrast enhanced film images of the gaps are shown by the broad white lines (unexposed areas) in Figure 7. The widths of the white lines in Figure 7 are proportional to the gap widths for gap sizes larger than approximately 2 mm, and are constant for gap sizes less than 2 mm; also the density contrast of the lines decreases as the gap widths decrease below 2 mm. This behavior can be expected with the camera spatial resolution of approximately 2 mm (as estimated with ray diagrams) which was imposed by the 1 mm camera slot and x-ray beam collimator widths. These results suggest that density plots of each film image, in the direction of the x-ray beam penetration depth into the test object, can provide data for determining gap sizes, even for gaps that may be smaller than the spatial resolution of the camera.

Figure 8 shows the microdensitometer plots of the six films in Figure 7, as a function of the penetration depth in the region of the gap. The densitometer scanning slit used for all traces was 0.16 x 1.35 mm. In these density plots, the gap sizes are proportional to the displaced peak areas which are superimposed on the exponentially shaped density curves as shown by the dashed line in Figure 8 (d); the peak area is the region below the dashed line. Graphical measurements of the relative peak areas for different gap sizes, are given in Figure 9, which shows a linear relationship between the relative peak areas and the gap size, and provides a quantitative method for determining gap sizes, even for separations that are small compared to the spatial resolution of the camera.

The second set of experiments was carried out with the multilayer test objects shown in Figure 5(B) and 5(C). The exposure conditions for each of these test objects is given in Table 1. For object 5(B), film images were obtained for three different geometries, as specified in Table 1 for the parameters given in Figure 1. Density plots of the films as a function of the penetration depth are given in Figures 10, 11 and 12. For each geometry, the gap positions confirm the ray diagram predictions, and indicate that delaminations may be accurately determined. In addition it is significant to note that delaminations may be magnified or demagnified simply by changing the distance ratio, B/A, defined in Figure 1, as indicated in the comparison of Figures 10 and 12. Also the spatial resolution of the slot camera may be varied in a simple manner by changing the distance ratio, B/A, the camera slot aperture, a, and the x-ray collimator width in a coordinated manner prescribed by simple ray diagrams.

The film image and the corresponding density plot obtained for the test object 5(C) is given in Figure 13; this clearly shows all of the gaps (white lines) to correspond with the test sample indicated in Figure 5(C), including the delaminated surfaces clamped together (zero gap). A very important advantage of the slot camera is that it provides the total depth structure of the material in a single exposure. The depth, d, from the object surface to any delamination is obtained from direct measurements on the film images of the penetration depth, D, in the beam direction from the object surface to the center of the low film density images (white lines) such that:

$$d = (A / B)(\cos \alpha) D \qquad (1)$$

where d = actual depth in the inspected object, perpendicular to the object surface.

A = x-ray beam to camera slot distance, Figure 1.

B = camera slot to image plane distance, Figure 1.

D = distance on the film (or other detector) from the indication of the object surface to the center of the indication of the delamination (or other anomaly).

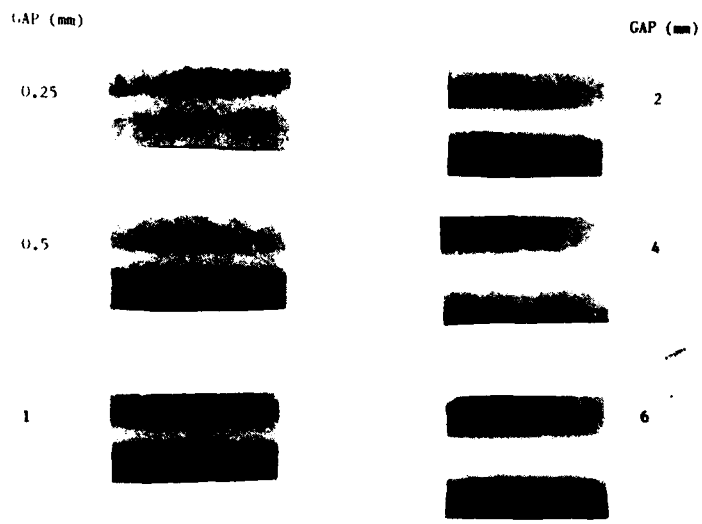

FIGURE 7. BACKSCATTER SLOT CAMERA FILM REPRODUCTIONS FOR SAMPLES SHOWN IN FIGURE 5A WITH VARIOUS GAPS (DELAMINATIONS). GAP SIZES WERE, LEFT COLUMN (TOP TO BOTTOM) 0.25, 0.5 AND 1.0mm. RIGHT COLUMN (TOP TO BOTTOM) 2, 4 AND 6mm

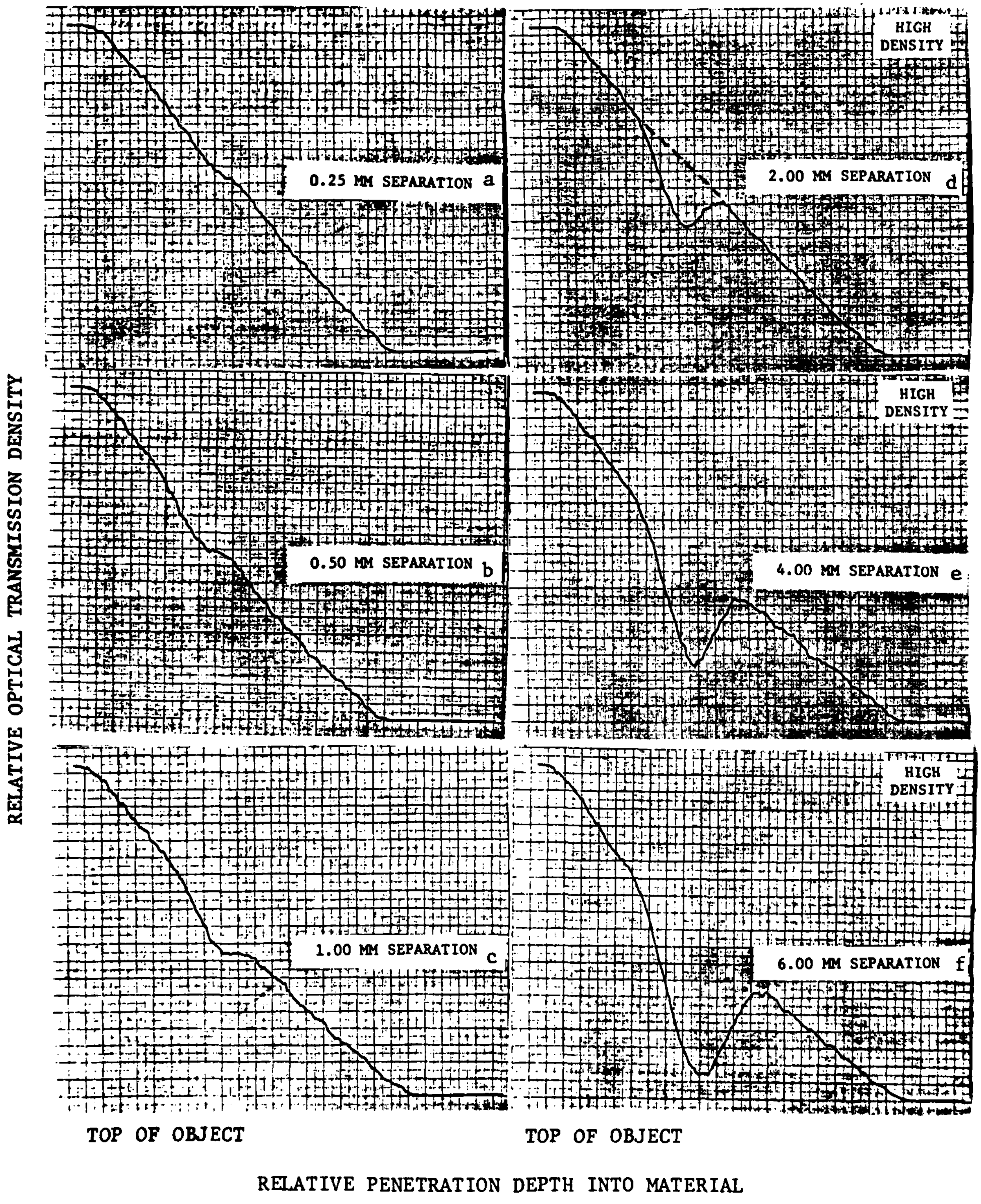

FIGURE 8. SCANNING MICRODENSITOMETER TRACES SHOWING GAP IMAGES PICTURED IN FIGURE 7 IN THE SAME ORIENTATION. DOWNWARD PEAKS REPRESENT THE DECREASED FILM DENSITY SHOWING THE GAP

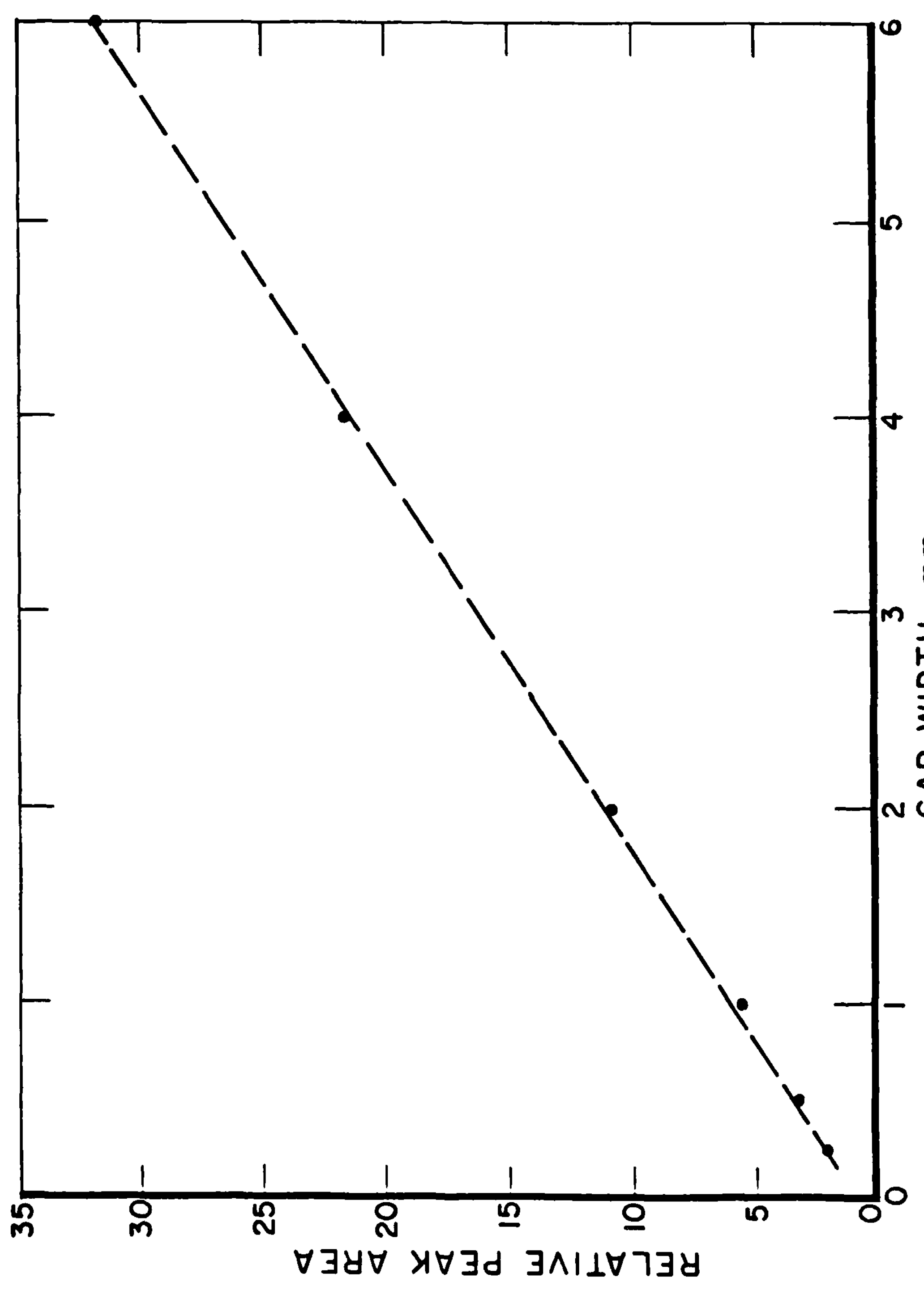

FIGURE 9. RELATIVE PEAK AREA, FOR DENSITY-DISTANCE PLOTS OF FIGURE 8 VERSUS GAP WIDTH

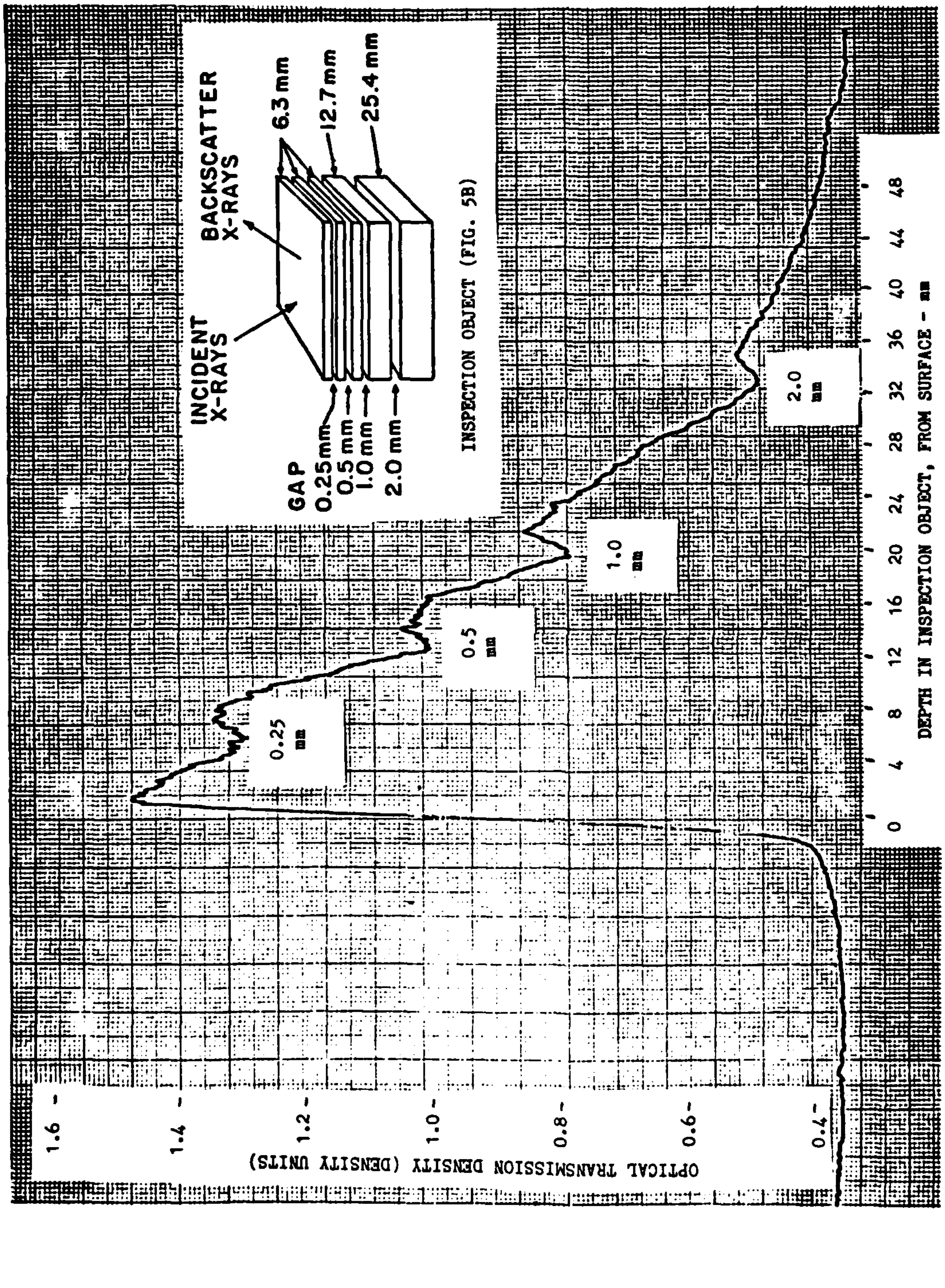

FIGURE 10. SCANNING MICRODENSITOMETER TRACE OF BACKSCATTER SLOT CAMERA IMAGE OF MULTI-LAYER TEST PIECE SHOWN IN FIGURE 5B. REDUCED DENSITY PEAKS CORRESPONDING WITH INDIVIDUAL GAP SIZES ARE INDICATED

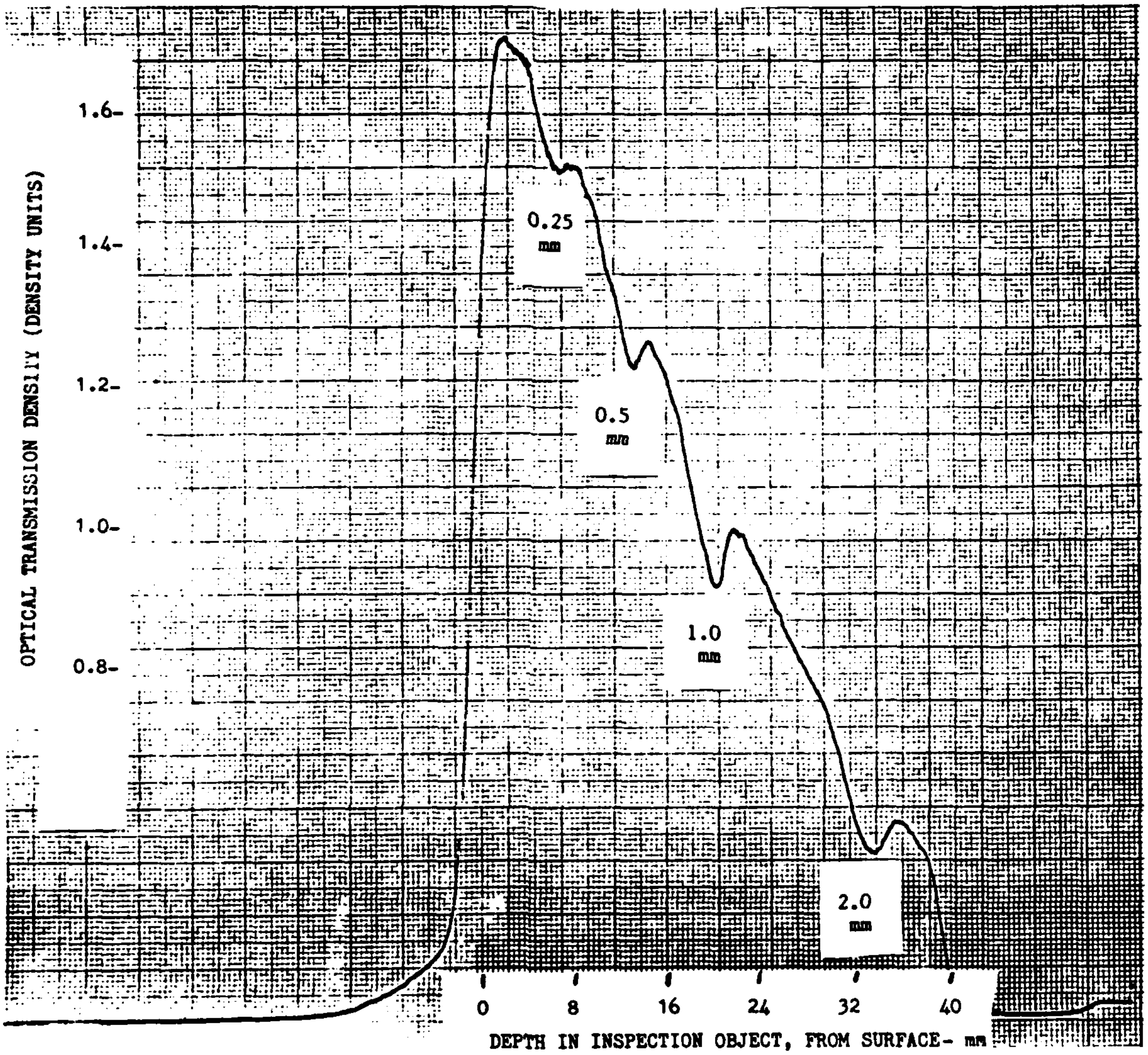

FIGURE 11. SCANNING MICRODENSITOMETER TRACE OF BACKSCATTER SLOT CAMERA IMAGE OF MULTI-LAYER TEST OBJECT SHOWN IN FIGURE 5(B). ANGLE OF INCIDENCE WAS CHANGED FROM 45 TO 60 DEGREES

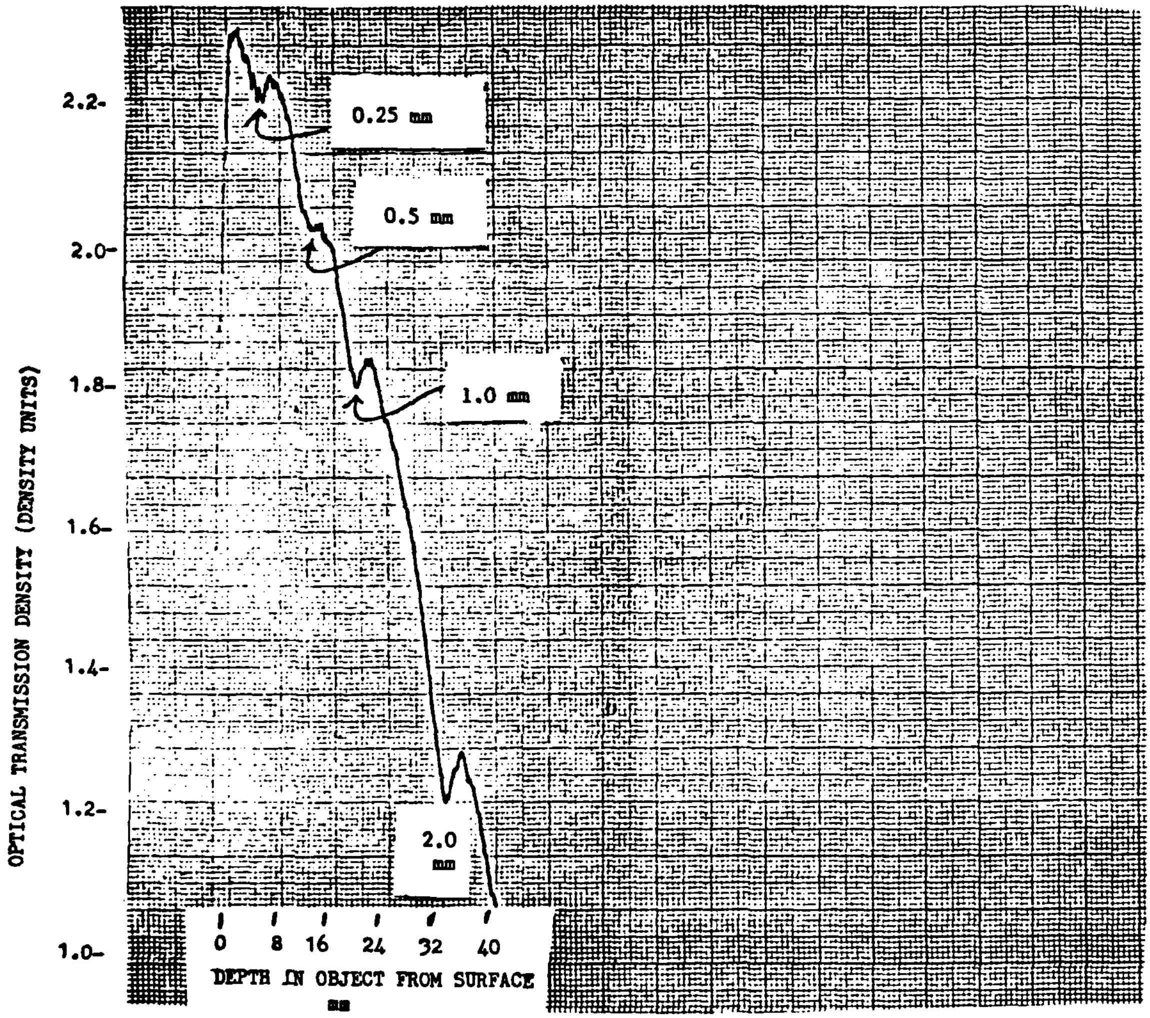

FIGURE 12. SCANNING MICRODENSITOMETER TRACE OF BACKSCATTER SLOT CAMERA IMAGE OF MULTI-LAYER TEST OBJECT SHOWN IN FIGURE 5(B). IMAGE MAGNIFICATION WAS CHANGED TO 1/2; THIS MOVES PEAKS CLOSER TOGETHER

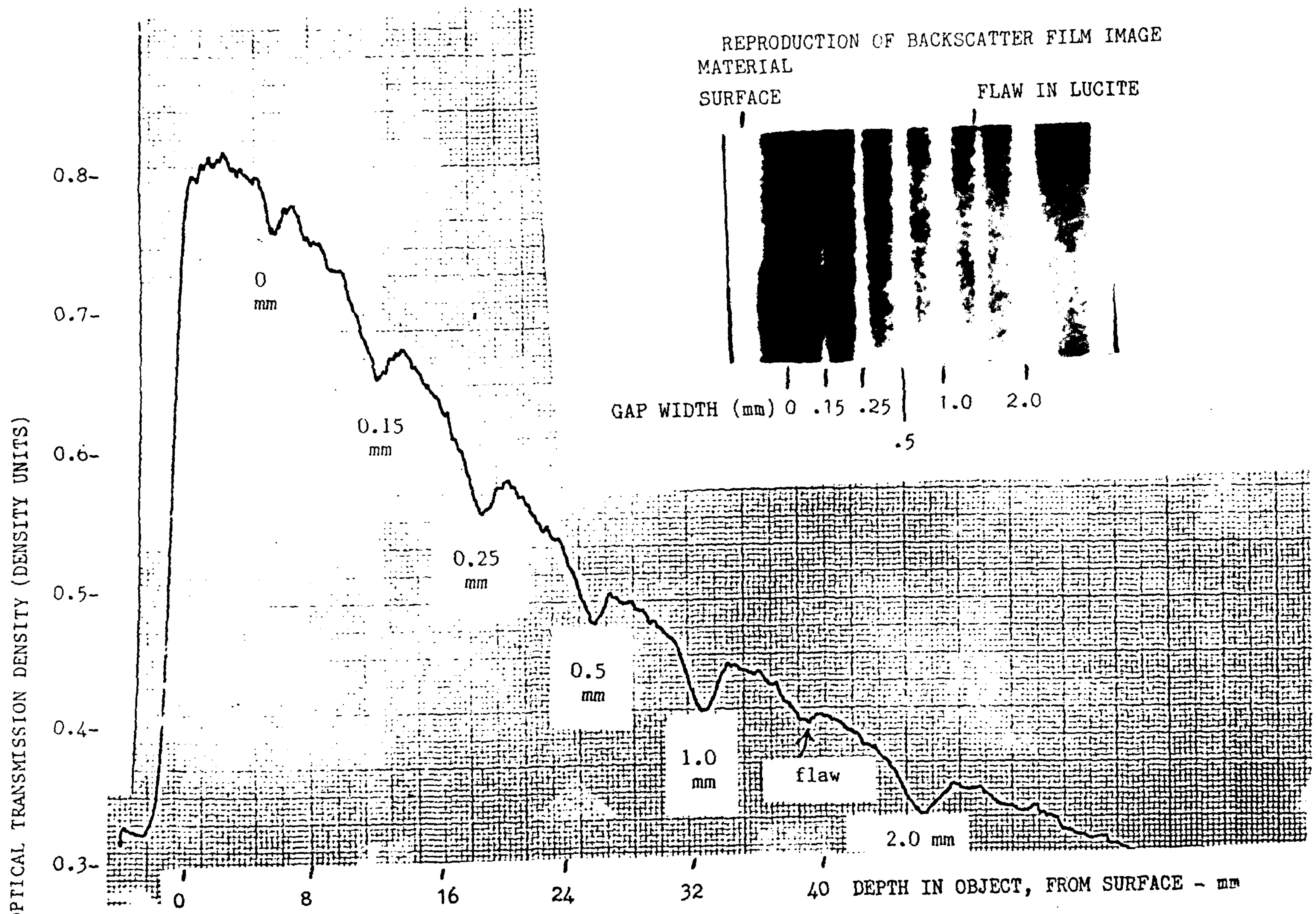

FIGURE 13. SCANNING MICRODENSITOMETER TRACE OF BACKSCATTER IMAGE OF MULTI-LAYER TEST OBJECT (FIGURE 5C) SHOWING CLEAR REDUCED FILM DENSITY IMAGS FOR GAP SIZES 0, 0.15, 0.25, 0.5, 1.0 AND 2.0 mm IN WIDTH, AS WELL AS UNINTENDED FLAW IN ONE LUCITE BLOCK. THE INSET SHOWS A REPRODUCTION OF THE BACKSCATTER FILM IMAGE

The experimental values of d for objects 5(B) and 5(C) are given in Table 2, from measurements of D on the slot camera films and from Eq. (1). In comparison, the actual values which were obtained from direct measurements on the test objects, agree well with the slot camera values. The delamination widths for separations larger than the spatial resolution may also be determined from direct film measurements and from Eq. (1). For separations smaller than the spatial resolution, it is necessary to use peak area methods described for test objects 5(A) and illustrated in Figures 8 and 9.

The final set of experiments was carried out with two clamped sections of the actual graphite-epoxy motor chamber shown in Figures 6A and 6B. The exposure conditions for this final test object are given in Table 1 (6A). The film image and the corresponding density plot for this test object are shown in Figure 14. The film clearly shows the ability of the slot camera to detect delaminations in graphite-epoxy motor cases. A separation was detected between the rubber backing of the top graphite-epoxy composite piece and the lower graphite-epoxy composite shell, even though the two pieces were clamped tightly together. Finally, a known separation between the lower graphite-epoxy composite and a backing Lucite block was detected 38 mm below the surface. In other related tests, images of separations more than 7 cm below the surface were detected.

DISCUSSION

EVALUATION OF RESULTS

Tests with graphite-epoxy composite material as used in rocket motor cases have shown that separations can be detected. A split sample, tightly clamped together, showed images of delaminations in the resultant scatter film (Figure 14). The scatter exposure from the rubber backing was different from that of the graphite-epoxy so that interface could be seen. A separation was detected between the rubber backing of the top graphite-epoxy composite piece and the lower graphite-epoxy composite shell, even though these were clamped tightly together. A known separation between the lower graphite-epoxy composite and a backing Lucite block was detected 38 mm (about 1.5 inch) below the surface. In tests with Lucite blocks, scatter signals as deep into the material as 7 cm (2.75 inch) were seen. Greater thickness penetration capability is available. This factor is dependent on x-ray energy, object density and imaging geometry.

Experiments at different imaging angles as illustrated in this report by the 60-degree view in Figure 11, have shown that the system is not overly sensitive to imaging geometry. It is desirable to keep the material path short for the scatter signal (to minimize attenuation and multiple scatter) and arrange the field of view in the camera to display the material depth of interest.

The experiments described have shown that the x-ray slot camera and its patented features[1] offer significant advantages. Previous work on x-ray inspection using scatter techniques has involved collimated beams and pin-hole camera approaches.[2-12]

Pin-hole camera techniques,[3,10] are useful but significantly slower in response as compared to the slot camera. The larger area slot permits more scattered photons to enter the camera and be detected. At the same time, the arrangement of the slot and the imaging geometry maintains good spatial resolution in the camera image.

TABLE 2. DELAMINATION DEPTHS FOR TEST OBJECTS

LUCITE OBJECT 5(B)		LUCITE OBJECT 5(C)	
ACTUAL*	SLOT CAMERA**	ACTUAL*	SLOT CAMERA**
(DIMENSIONS IN mm)		(DIMENSIONS IN mm)	
6	6	6	7
13	13	13	13
20	18	20	20
34	31	26	28
		33	34
		49	49

* ACTUAL: VALUES MEASURED DIRECTLY ON OBJECT

** SLOT CAMERA: VALUES OBTAINED FROM EQ. (1) WITH CONDITIONS IN TABLE 1

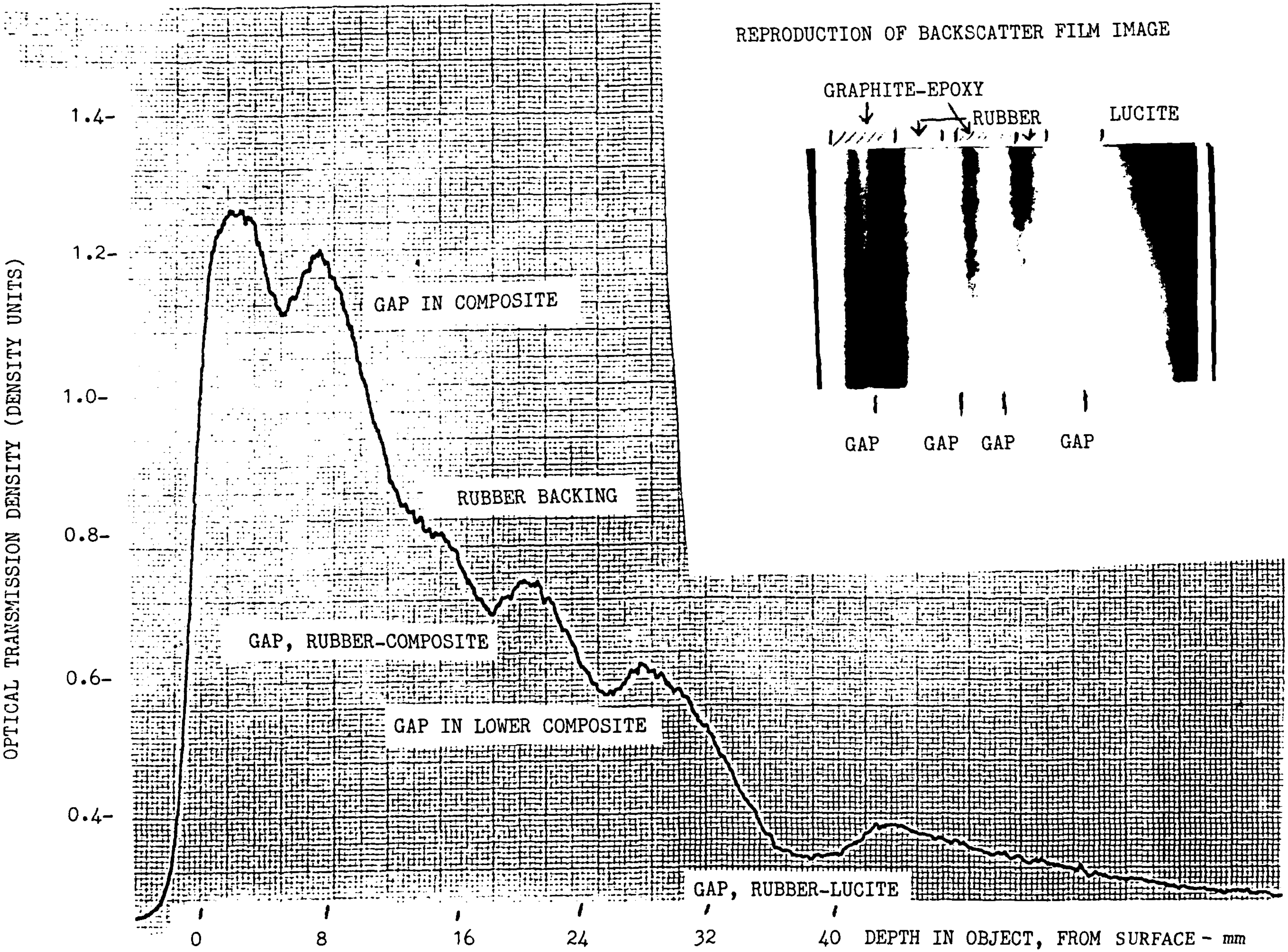

FIGURE 14. SCANNING MICRODENSITOMETER TRACE OF BACKSCATTER SLOT CAMERA IMAGE OF COMPOSITE SAMPLE (FIGURE 6A). THERE WERE NO INTENTIONAL GAPS IN THE GRAPHITE-EPOXY SAMPLE; PIECES WERE CLAMPED TOGETHER TIGHTLY. THE INSET IS A REPRODUCTION OF THE BACKSCATTER IMAGE

Compton scatter techniques,[8,11,12] are now well developed and have been applied to inspections of items such as artillery shells. For applications such as that, very high output radiation sources and multiple inspection stations have been required to obtain reasonable inspection through-put. For application to the inspection of composite rocket chamber walls, the slot camera offers a significant advantage over the Compton scatter approach in that the slot camera images the complete wall thickness of the rocket chamber in one view. The Compton scatter technique would require inspection at each designated thickness element throughout the wall of the motor.

Tomographic inspection[13] is another alternative technique to inspect rocket motors. For internal details, this approach is particularly useful since total interrogation of the motor is required. It is, of course, necessary to gain access to all sides of the inspection object and do through-transmission tests from many different angles. A high energy x-ray source such as a linear accelerator is necessary to penetrate a large motor.[14] This can reduce sensitivity to relatively small delaminations. The backscatter slot camera provides useful information on delamination depth and size in a simpler presentation and requiring access from only one side of the inspected object.

DESIGN OF AN ELECTRONIC CAMERA

Figure 2 illustrated the pixel geometry of the imaging system and provides one basis for the design of an electronic camera. Individual detectors to match the rectangular pixels will be designed. The detector is presently envisioned as an array of rectangular-shaped scintillation counters. A counting detector will offer excellent sensitivity.

In terms of improved sensitivity the electronic camera will be capable of inspection periods in the order of seconds or less. In the experiments reported here the maximum film exposure time used was about two hours. Previous measurements have shown that an x-ray exposure of 1mR incident on the screen-film system is required to produce a film density of unity. Therefore, if we assume 60keV x-rays as the major part of the scattered signal, 1mR is equivalent to 3×10^7 x-ray photons per cm^2 incident on the screen film system, over a period of 2 hours ($\sim 7 \times 10^3$ seconds). Then the input x-ray flux is $\sim 4 \times 10^3$ photons per cm^2 - second. Since the slot area (or pixel area) is approximately 2 cm^2, we have 8×10^3 photons per second per pixel. If we assume conservatively that the x-ray detector has 30% detection efficiency, the number of detected x-ray photons per pixel per second is about 2×10^3, which corresponds to a signal-to-noise ratio of about 40. This illustration provides a high confidence level for the successful development of an electronic slot camera instrument. The new electronic camera proposed will yield a digital signal in terms of the counts from each pixel. This will make it possible for ready application of digital signal processing techniques to bring out additional details in the image.

CONCLUSIONS

The Phase I program has demonstrated that the slot camera one-sided x-ray inspection system has the capability of detecting and quantifying delaminations in low atomic number test samples. Gaps detected have varied from contact separations of two flat-faced samples to separations larger than 6 mm. These may occur at different depths below the object surface ranging from 0 to 7 cm or more. In addition,

this inspection system provides data which give quantitative estimates both of the depth below the object surface at which the delaminations occur and of the sizes of the delaminations. The camera has the ability to magnify or demagnify the image; also it demonstrates a spatial resolution which can be changed simply by changing the slot aperture and the beam width with a corresponding tradeoff in the exposure time required for obtaining an image.

In summary, the feasibility investigation has shown that variations in density can be detected in a one-sided inspection by the x-ray slot camera. The quantitative data available provide information about discontinuity location and size. The detection approach display shows in a single view a discontinuity or multiple discontinuities throughout the total thickness of the inspected wall.

For the specific problem of detecting and assessing damage in composite walls of rocket motor cases, the slot camera concept offers the promise of a real-time, quantitative inspection. Further developments proposed involve an electronic detector to replace film. This will provide a practical fast-response inspection instrument to assess damage to rocket motor case walls in the plant or in field locations. Prospects for development of a transportable instrument are favorable.

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